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THE USE OF ERTS IMAGERY TO MONITOR SURFACE MINING OF COAL IN NO--ETC(U)

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THE USE OF ERTS-1 IMAGERY TO MONITOR SURFACE  
MINING OF COAL IN NORTH CENTRAL TENNESSEE

A Thesis  
Presented to  
the Graduate Council of  
The University of Tennessee

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

by  
Cpt. James Thomas Ralph Johnson, Jr.

June 1974

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⑥

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MINING OF COAL IN NORTH CENTRAL TENNESSEE.

⑨

Master's Thesis,

⑫

66 p.

A Thesis

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## ABSTRACT

This investigation evaluates the utility of simple, human visual interpretation procedures in deriving county-wide strip mining acreage estimates from ERTS-1 imagery. It evaluates the inherent accuracies obtained for a five county study area in North Central Tennessee. Related geographic ERTS investigations are reviewed and potential applications of ERTS suggested by this study are indicated.

Two approaches to deriving mining acreages were examined: a point sampling technique and an areal estimation sampling procedure. For the study area, the point sampling technique was found to be faster and more accurate.

The inherent advantage of ERTS imagery is provision of cyclic, synoptic coverage on a timely basis. The principal limitation is the relatively low resolution level of the ERTS imagery as compared to larger scale, lower altitude aircraft remote sensing capabilities. It is hoped that this study will serve to help geographers, conservationists, planners and others to gain an understanding of the landuse information content available through use of simple interpretation techniques from small-scale ERTS imagery.



#### ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to Professors Thomas L. Bell and James R. Carter. Special appreciation is extended this writer's advisor and Major Professor, Dr. John B. Rehder, for his guidance, suggestions and encouragement.

The writer is also in the debt of personnel at the TVA Forestry and Reclamation Divisions, particularly Mr. Al Bateson, the personnel in the Knoxville Office of the Tennessee State Bureau of Mines, including Mr. Bob Johnson, Director, and Mr. Herman Sain and Mr. Ken Totty, Inspectors; and the personnel at the East Tennessee Office of the State Division of Geology, especially Mr. Ray Leamon.

## TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION AND STUDY PURPOSE . . . . .	1
Introduction. . . . .	1
Purpose . . . . .	3
The Study Area. . . . .	5
Procedure . . . . .	9
II. ERTS IMAGERY AND CONTOUR STRIP MINING	
OPERATIONS. . . . .	10
ERTS System Description . . . . .	10
ERTS Landscape Studies. . . . .	16
Contour Strip Mining Operations . . . . .	18
III. INTERPRETATION TECHNIQUES AND RESULTS. . . . .	26
Imagery Selection . . . . .	26
Mine Site Recognition . . . . .	29
Point Sampling of Total Disturbed Acreage . . . . .	31
Areal Estimation Sampling of Total Disturbed Acreage. . .	37
Seasonality of Interpretation . . . . .	38
Summary . . . . .	42
IV. SUMMARY AND CONCLUSIONS. . . . .	45
Summary . . . . .	45
Conclusions . . . . .	48
V. BIBLIOGRAPHY . . . . .	51
VI. VITA . . . . .	58

# LIST OF TABLES

TABLE	PAGE
1. SUMMARY OF PRODUCT TYPES AND FORMAT - ERTS . . . . .	15
2. CHANGES IN TOTAL ACREAGE DISTURBED BY CONTOUR STRIP MINING OF COAL RESERVES . . . . .	20
3. ACTUAL DISTURBED ACREAGE TOTALS CORRESPONDING TO ERTS COVERAGE DATES . . . . .	25
4. USABLE ERTS MSS-7 IMAGERY AVAILABLE FOR STUDY AREA . . .	27
5. POINT SAMPLING ESTIMATES OF MINED ACREAGES FOR EACH COVERAGE PERIOD . . . . .	33
6. POINT SAMPLING ESTIMATES OF PERCENT MINED AREA . . . . .	35
7. COMPARISON OF ACTUAL VERSUS POINT SAMPLING ESTIMATES OF PERCENT CHANGE IN DISTURBED ACREAGE. . . . .	36
8. RESULTS OF AREAL ESTIMATION SAMPLING OF 12 JULY 1973 ERTS WITH POINT SAMPLING COMPARISON . . . . .	39



## LIST OF FIGURES

FIGURE	PAGE
1. The Study Area, Located in the Northern Half of the Tennessee Portion of the Cumberland Plateau . . . .	6
2. Typical ERTS Daily Ground Trace - Daylight Passes Only . . . . .	11
3. ERTS MSS Coverage (4 Bands) for Knoxville on 12 July 1973 . . . . .	13
4. Typical Contour Strip Mining Site . . . . .	22
5. Representative Seasonal Coverage for ERTS MSS-7 . . . .	41

## CHAPTER ONE

### INTRODUCTION AND STUDY PURPOSE

#### I. Introduction

Tennessee has abundant coal deposits, currently being exploited and programmed for use against the increasing demands projected for the next two decades. Because of the character of strip mines, size of equipment, quantities of earth removed in the process, speed of operations, and readily visible marks left on the landscape, strip mining is viewed with concern. As more areas come under the pressure for development, it is important that all means to monitor and assess the impact of the surface mining of these reserves be considered.

Use of small-scale remote sensing imagery to monitor the landscape began as a spinoff from the U. S. space program. In July, 1972, the Earth Resources Technology Satellite (ERTS-1) was launched, and began to monitor the earth's surface. More recently, SKYLAB flights have included earth resources surveys.

The advent of ERTS-1 imagery has presented a new opportunity for geographic study of land use at a regional perspective and from a higher, near-orthogonal vantage point.

Prior to launch only one researcher, Dr. John B. Rehder, submitted a proposal to the National Aeronautics and Space Administration (NASA) specifically aimed at studying land use change on ERTS imagery. His work to date has demonstrated that strip mining changes can be detected by study of individual mine sites through successive ERTS frame coverage.<sup>1</sup>

After several cycles of ERTS imagery had been examined, other investigators noted the potential applications of ERTS to the study of strip mining activities. Gilbertson is attempting to differentiate between mining dumps on the basis of amount of vegetative cover.<sup>2</sup> Preliminary work in Indiana indicates that regional strip mining inventories from ERTS appear feasible.<sup>3</sup> Initial efforts are underway to map strip mining and reclamation activities from ERTS in Eastern Ohio.<sup>4</sup> ERTS imagery is being used to map extent of strip mines and

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<sup>1</sup>John B. Rehder, "Applications of ERTS-1 Data to Landscape Change in Eastern Tennessee," Proceedings of Symposium on Management and Utilization of Remote Sensing Data (Sioux Falls, S.D.: American Society of Photogrammetry, 1973), p. 599.

<sup>2</sup>Brian Gilbertson, "Monitoring Vegetative Cover on Mine Dumps with ERTS-1 Imagery: Some Initial Results," Proceedings of the Symposium on Significant Results Obtained from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 577.

<sup>3</sup>Charles Wier, Frank J. Wobber, Orville R. Russel, and Roger V. Amato, "Fracture Mapping and Strip Mine Inventory in the Midwest by Using ERTS-1 Imagery," Proceedings of the Symposium on Significant Results Obtained from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 557.

<sup>4</sup>Phillip E. Chase and Wayne Pettyjohn, "ERTS-1 Investigation of Ecological Effects of Strip Mining in Eastern Ohio," Proceedings of the Symposium on Significant Results Obtained from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 561.

to study effectiveness of reclamation and pollution abatement procedures in Pennsylvania.<sup>5</sup>

Considering the fact that ERTS imagery has only been available for shortly over one year it appears that considerable interdisciplinary work is ongoing in applications of ERTS to monitoring of strip mining related activities. It has been demonstrated that ERTS imagery can be used for small-scale monitoring of strip mining. One question that follows is, "What level of detail and precision can be gained from this source through manual processes?" ERTS reports have thus far not provided statistics on the accuracy obtained from ERTS data.

## II. Purpose

The purpose of this thesis is to evaluate the usefulness of ERTS-1 imagery as a means of monitoring surface mining of coal in north central Tennessee. Specifically, the following questions will be pursued:

- (1) Using point sampling and areal estimation procedures, how accurate are static estimates of mining acreages taken from ERTS-1 imagery?
- (2) Is the precision of interpretation from ERTS in giving static acreage estimates adequate to derive acceptable estimates of acreage changes through time?

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<sup>5</sup>S. S. Alexander, J. Dien, and D. P. Gold, "The Use of ERTS-1 MSS Data for Mapping Strip Mines and Acid Mine Drainage in Pennsylvania," Proceedings of the Symposium on Significant Results Obtained from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center), 1973, p. 569.



(3) What other land use applications does the study indicate ERTS imagery may provide?

There are two current schools of thought regarding analysis of data such as contained on ERTS records. One is that such data is best treated by human image analysts. The other approach is that due to the vast amount of data available, direct computer analysis techniques are best. Both human visual analysis and machine processing have application to the problems of interpretation. Within each approach procedures with differing degrees of complexity can be pursued. Much promise is held for sophisticated electronic and photographic imagery enhancement approaches to photo interpretation, however these methods are not within the scope of this study. This study is limited to use of simple, human visual techniques of photo interpretation. It demonstrates how accurately areal extent of mines can be estimated using simple, visual, hand interpretation techniques and sampling procedures. They should be easily comprehended and are widely available for use by skilled personnel, such as geographers, geologists, conservationists, and planners.

In selecting imagery for later detailed study, only the bulk and precision imagery received directly from the ERTS Photographic Processing Facility in Sioux Falls, South Dakota was considered. Use of darkroom facilities to produce enhanced positive or negative prints may be meaningful, but will not be considered here.

### III. The Study Area

A study area consisting of five contiguous counties in the northern plateau area of Tennessee was selected (Figure 1). This region contains approximately 80% of the total strip mine acreage in the state of Tennessee. The demonstrated relationship between small scale, imagery-derived mining acreages and actual acreages will have application to surface mining activities throughout Tennessee and possibly to other mining areas of the Eastern United States.

The five-county study area is situated in the northwest corner of the Tennessee section of the Cumberland Plateau. Actually the eastern portions of Claiborne and Anderson Counties lie east of the Plateau and strip mining operations are situated in the western, plateau portions of these two counties. The total area occupied by the five counties is 1,480,400 acres. Total area disturbed by strip mining of coal as of 12 July, 1973 was 41,320 acres, ranging from a low total of 5,155 acres for Claiborne County to a high of 14,229 acres for Campbell County.<sup>6</sup>

The study area has a mean annual precipitation of 50 inches. Maximum rainfall occurs in March and August, however it is well distributed throughout the year with no month averaging less than

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<sup>6</sup>Reported acreages as determined by actual ground surveys by personnel of the Tennessee Division of Geology.

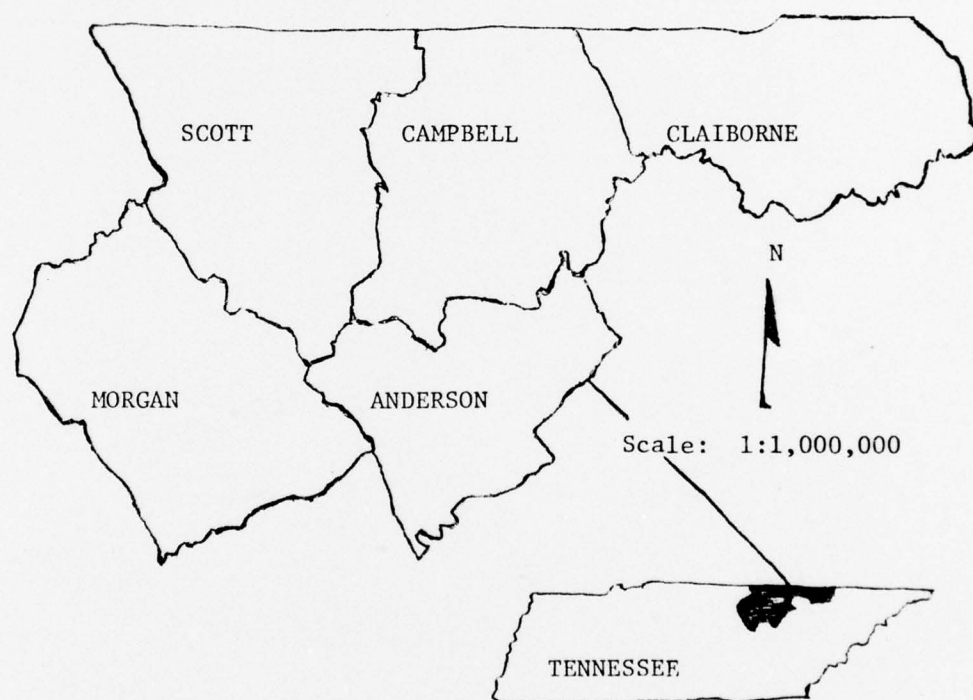


Figure 1. The Study Area, Located in the Northern Half of the Tennessee Portion of the Cumberland Plateau.

three inches.<sup>7</sup> The mean frost-free period is 173 days. The mean seasonal temperatures range from a monthly average of 73° F. in July to 37° F. in January, a range of 36° F. The winters are mild — the ground is seldom snow covered more than a few days and the soil only freezes shallowly. Temperatures fall at or below 32° F. for an average of 80 days per year.<sup>8</sup>

The study area lies within the Appalachian Highlands Physiographic Region.<sup>9</sup> USGS topographic map sheets (1:24,000) were used to determine slope and local relief characteristics of the study area. All or portions of 51 quadrangles cover the study area and a 20% sample of ten sheets was taken to determine the area's slope distribution and relief features. Since strip mining activities are limited to the plateau portion of the study area, no sample sheets were taken from the eastern sections of Claiborne and Anderson Counties which lie in the Great Valley of the Tennessee River. Slope sampling procedures and sample sizes of 60-100 points were used as outlined by Hammond.<sup>10</sup>

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<sup>7</sup>"Climatological Data," U.S. Weather Bureau (Washington, D.C.: U.S. Department of Commerce, 1972), pp. 145-50.

<sup>8</sup>Climatological Atlas of Continental U.S., Vol. I (New York, N.Y.: Weather Trends, Inc., 1964).

<sup>9</sup>Edwin H. Hammond, "Classes of Land-Surface Form in the United States," The National Atlas of the United States of America (Washington, D.C.: United States Geological Survey, 1970), p. 61.

<sup>10</sup>Edwin H. Hammond, Procedures in the Descriptive Analysis of Terrain, Final Report (Washington, D.C.: Geography Branch, Earth Sciences Division, Office of Naval Research, 1958).



The slope distribution was found to be as follows: 7% of area in 0-8% slopes, 12% of area in 8-15% slopes, 17% of area in 15-30% slopes and 64% of area in slopes of greater than 30%. The predominant class is that of steep slopes, greater than 30% slope. Furthermore, 81% of the plateau portion of the study area is in slopes of 15% or more. The mean elevation of the plateau portion of the study area is 2,150 feet; local relief differences range from 700 to 1,300 feet.

The study area is underlain by folded strata, resulting in rugged topography. These strata consist of limestones, dolomitic limestones, shales and sandstones. The area is chiefly drained by the Cumberland River System, although the southeastern portion is in the Tennessee River Valley. The soils of this upland area have developed under warm temperatures, high rainfall and predominantly deciduous vegetation. They are characterized by gray brown silt loams and are highly leached. The area's soils are distributed as 20% silt loams, 22-45% cherty silt loams, 5-20% stony fine silt loams, up to 10% fine sandy loams, 5% silty clay loams and 11-19% miscellaneous land types.<sup>11</sup>

Approximately 90% of the study area is forested. Except for roads, small hamlets, and the strip mined areas the upland areas are forested. Forest vegetation is mixed, with a predominance of hardwoods.

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<sup>11</sup>Morris E. Austin, Soil Survey, Claiborne County, Tennessee (Washington, D.C.: Government Printing Office, 1948), pp. 3-29, and Foster Rudolph, Soil Survey, Norris Area, Tennessee (Washington, D.C.: Government Printing Office, 1953), pp. 3-11.

The area has been selectively logged for the largest saw timber and subsequently scattered conifer and second growth hardwood stands have become established.

#### IV. Procedure

Initially, imagery for every available ERTS coverage date was examined. Most frames were eliminated because of poor weather conditions. Seven dates were deemed to be of sufficient quality to be usable in the study. These frames were sampled directly and static acreage estimates extracted by point and areal techniques. Estimated mine site acreages are compared to actual disturbed acreages obtained from Tennessee Bureau of Mines figures. Apparent change through time as measured on the photos is also compared to actual disturbed acreage changes from field reports. Complete data was made available for each mining operation, through the Tennessee Bureau of Mines office in Knoxville. This data served as the "ground truth" basis of analysis of the accuracy of ERTS derived estimates.

## CHAPTER TWO

### ERTS IMAGERY AND CONTOUR STRIP MINING OPERATIONS

#### I. ERTS System Description<sup>1</sup>

The ERTS-1 satellite was launched in July, 1972 into a circular, sun synchronous, near-polar orbit of about 500 nautical miles altitude. It circles the earth every 103 minutes, completes 14 orbits per day and the satellite ground trace repeats its coverage every 18 days. A representative ground trace for one day is shown in Figure 2. A result of the ERTS' sun synchronous orbit is that the time at each coverage point remains fixed; therefore each frame of the study area has been taken at approximately 9:40 A.M., mean sun time. This does much to enhance comparability of successive frames covering the area, as it reduces lighting and shadow differences. It does not, however, account for seasonal changes in the local solar elevation angle at the constant exposure time. For the study area the solar elevation angles at exposure time are 37° in January, 52° in April, 58° in July and 40° in October. The effects of these changing elevation angles are dependent on the earth scene composition. For example, the reflectance of sand is much more sensitive to these changes than is most vegetation.

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<sup>1</sup>The information contained in this section was taken from the ERTS Data Users Handbook, prepared by the EROS Program, United States Geological Survey, Greenbelt, Maryland: NASA/Goddard Space Flight Center, 1971.

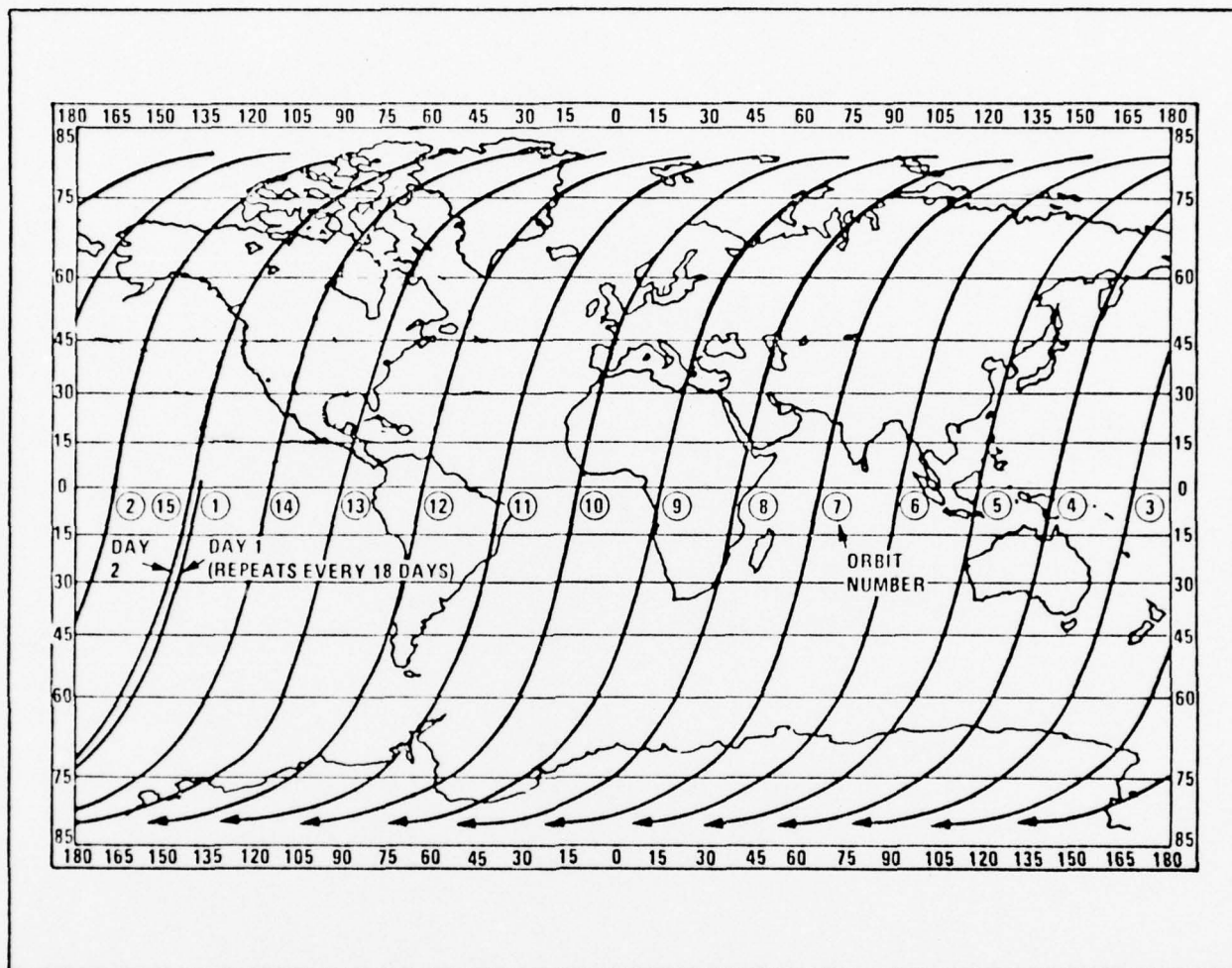


Figure 2. Typical ERTS Daily Ground Trace - Daylight Passes Only  
(Source: ERTS Data Users Handbook).



The sensor system consists of a four band scanner operating in the solar reflected region of wavelengths from 0.5 to 1.1 micrometers.<sup>2</sup> This multispectral scanner system (MSS) gathers data by imaging the earth in four bands simultaneously: Band 4, 0.5 to 0.6 micrometers (green); Band 5, 0.6 - 0.7 micrometers (red); Band 6, 0.7 - 0.8 micrometers (near infrared); Band 7, 0.8 - 1.1 micrometers (infrared). Photographic products from the four bands are shown in Figure 3 for the Knoxville frame of 13 July, 1973. Bands four, five and six use photomultiplier tubes for detectors, band seven uses photodiodes.

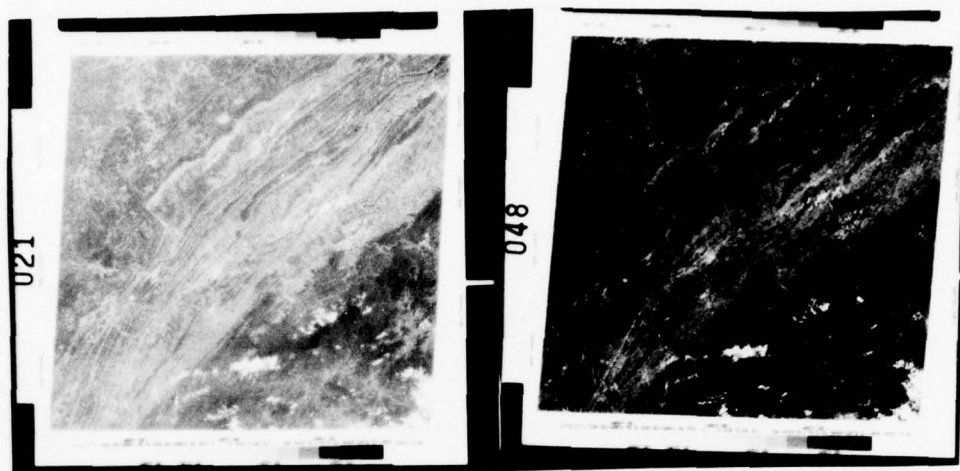
The instantaneous field of view for each detector is an earth area square 79 meters on a side. Each ERTS imagery frame covers an area of about 100 x 100 nautical miles. The cross track swaths are imaged by scanner mirror oscillation; the along track scan is produced by orbital motion. The inherent MSS errors have a maximum combined effect of  $\pm 26$  meters of true ground location.

A data collection system collects and disseminates data transmitted from the ERTS platform. ERTS signals use error coding to prevent the possibility of validating interference or incomplete messages. The probability of the system accepting an invalid transmission is less than 0.001.

The Photographic Processing Facility accepts original processed film images and produces large volumes of imagery products for

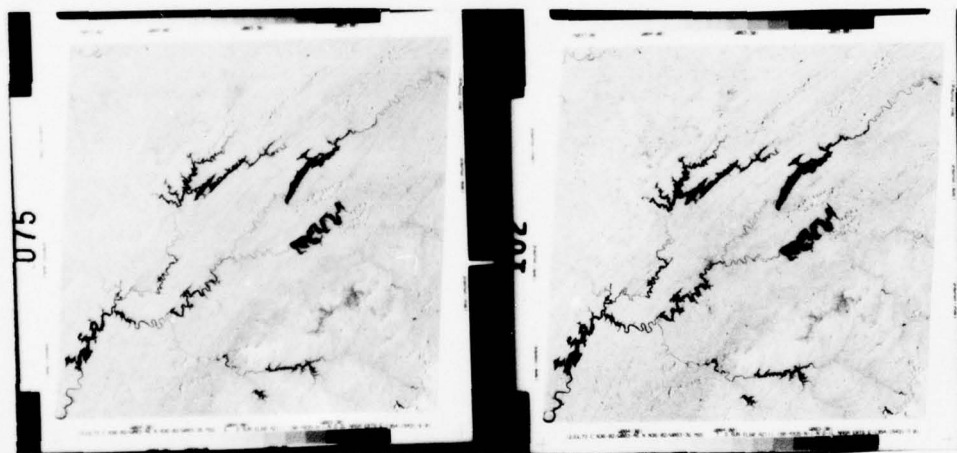
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<sup>2</sup>The ERTS-1 satellite also contains a second, television sensor, the Return Beam Vidicon System. However, due to technical problems it has not operated since the first week after launch.



Band 4

Band 5



Band 6

Band 7

Figure 3. ERTS MSS Coverage (4 Bands) for Knoxville on 12 July 1973. (70 mm format at scale of 1:3,800,000).

shipment to users; the imagery used in this study came from this facility. A summary of imagery products available is provided in Table 1. The MSS data is also available in the form of seven or nine track computer compatible tapes. The 70 mm format represents a scale of 1:3,800,000 and the 9.5" format is at a scale of 1:1,000,000. As noted in Table 2, the 9.5" image format is available in either bulk or precision processing form. Bulk imagery represents the earth scene as registered by the sensor. Precision imagery is geometrically adjusted by stretching the earth scene to remove a portion of the earth distortions introduced by the system, thereby providing a more cartographically correct image. Unfortunately the precision adjustment process results in a loss of detail.

The MSS maximum inherent error is +26 meters. Other possible ERTS spacecraft errors are in sensor alignment, instantaneous position, exact time of exposure and exact satellite altitude. The resultant maximum error from all these other sources is 1,052 meters. The maximum possible ERTS system error for a given ground location is 1,085 meters for bulk products and 250 meters for precision products; the maximum possible band to band registration error for any ground point is 155 meters for bulk products and 150 meters for precision products. These total error figures seem considerable, however, they represent the maximum possible system error and so less actual error for a given case can be expected.

TABLE 1

## SUMMARY OF PRODUCT TYPES AND FORMAT - ERTS

Processing Method	Format		
	Negative	Transparency	Print
Bulk	Black and White 70 MM Negative	Black and White 9.5" x 9.5" Positive Transparency	Black and White 9.5" x 9.5" Positive Print
Precision	Black and White 9.5" x 9.5" Negative	Black and White 9.5" x 9.5" Positive Transparency	Black and White 9.5" x 9.5" Positive Print
Bulk Color	N/A	Color 10" x 10" Positive Transparency	Color 10" x 10" Positive Print
Precision Color	N/A	Color 10" x 10" Positive Transparency	Color 10" x 10" Positive Print
Bulk	Black and White 70 MM Negative	Black and White 70 MM Positive Transparency	N/A

Source: ERTS Data Users Handbook



## II. ERTS Landscape Studies

ERTS investigators are pursuing areas of geographic interest other than strip mining. A new 1:500,000 map series has been proposed based primarily on ERTS imagery.<sup>3</sup> One of the greatest problems in mapping land use is to complete projects rapidly enough so that they are still of current value. Recent work by Estes and Senger has developed indicators for study of the nature and characteristics of regions.<sup>4</sup> Currently Wisconsin and Minnesota are integrating the use of ERTS data into the updating of their land inventory programs.<sup>5</sup> Finally a color-coded landuse map of northern Megalopolis is being completed from ERTS data.<sup>6</sup>

It is important to view man's environment from various distances and perspectives. Recently some geologic lineaments have been recognized

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<sup>3</sup>Alden P. Colvocoresses, "The ERTS Image Format as the Basis for a Map Series," Proceedings of the Symposium on Management and Utilization of Remote Sensing Data (Sioux Falls, S.D.: American Society of Photogrammetry, 1973), p. 142.

<sup>4</sup>John E. Estes and Leslie W. Senger, "Remote Sensing in the Detection of Regional Change," Proceedings of the Eighth International Symposium on Remote Sensing of Environment (Ann Arbor, Mich.: University of Michigan, 1973), p. 320.

<sup>5</sup>Robert B. Simpson and David T. Lindgren, "Land Use and Mapping," Summary of Significant Results from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 102.

<sup>6</sup>Robert B. Simpson and David T. Lindgren, "Land Use of Northern Megalopolis," Symposium on Significant Results from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 979.

on ERTS imagery which had previously gone unrecognized, even on U-2 high altitude aircraft imagery.<sup>7</sup>

Pollutants of the land, waters and air may be recognized directly or through surrogate features. A broader, regional review can be developed here through the aid of remote sensing. Current work includes use of ERTS-1 data to inventory California wildland resources.<sup>8</sup> It is obvious that new inferences concerning resource utilization and ecology are evolving from space-oriented study of photographs of the pattern of man-altered landscape.<sup>9</sup>

Man must inventory and record deposits and resources of the earth to more effectively meet the growing population's needs. Broad surveys of Alaskan resources are currently being accomplished using ERTS data.<sup>10</sup> Such integrated surveys serve as environmental, social and economic assessments of the assets and liabilities of a region's resources and delimit conditions within which development

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<sup>7</sup> Lawrence H. Lattman, "Mineral Resources, Geologic Structure and Landform Surveys," Summary of Significant Results Obtained from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 114.

<sup>8</sup> Donald T. Lauer and Paul F. Krumpe, "Testing the Usefulness of ERTS-1 Imagery for Inventorying Wildland Resources in Northern California," Proceedings of the Symposium on Significant Results from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 100.

<sup>9</sup> James P. Latham, "Urban Applications of Remote Sensing," The Geographical Review, LXI (January, 1971), p. 291.

<sup>10</sup> John M. Miller and Albert E. Belon, "A Multidisciplinary Survey for the Management of Alaskan Resources Utilizing ERTS Imagery," Proceedings of the Symposium on Significant Results from ERTS-1 (Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973), p. 1004.

and conservation decisions are made.<sup>11</sup>

Expansion in effective use of all resources depends on enlarged knowledge of their distribution and character . . . the capabilities of remote sensors in Earth orbit can make significant contributions relative to these exploration tasks.<sup>12</sup>

### III. Contour Strip Mining Operations

The first contour stripping in Tennessee came about during World War I. It was conducted at a small scale, using hand and animal powered techniques. Immediately following World War II, heavy earth handling equipment, including bulldozers and frontloaders began to be used.<sup>13</sup> A greatly increased freight rate structure for rail movement of coal seems to have kept the coal industry in Tennessee from expanding significantly during the period 1945-1959. New freight rate schedules, much more favorable to the rail shipment of coal, were adopted in the late 1950s.<sup>14</sup> This factor, along with the growing need to supplement the area's hydroelectric power output with thermoelectric power generation, seems to have spurred the

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<sup>11</sup>Charles J. Robinove, "Remote-Sensing Potential in Basic Data Acquisition," Water Resources Bulletin, III (July, 1967), p. 32.

<sup>12</sup>Peter C. Badgley and William L. Vest, "Orbital Remote Sensing and Natural Resources," Photogrammetric Engineering, XXXII (September, 1966), p. 784.

<sup>13</sup>"An Appraisal of Strip Mining," Tennessee Valley Authority (Knoxville, Tennessee, 1963), pp. 4-5.

<sup>14</sup>"Strip Mining in Kentucky," The Strip Mining and Reclamation Commission (Lexington, Ky.: Division of Strip Mining and Reclamation, 1965), p. 21.

Tennessee coal industry to begin rapid expansion, particularly in the area of surface mining activities. Table 2 indicates the rapid expansion of disturbed acreage within the study area for the period of 1961-1973.

Strip mine production in the study area rose from 911 million tons in 1959 to 2,538 million tons in 1968, nearly a three-fold increase. In 1968, the study area produced 77% of Tennessee's total strip mine tonnage. The coal produced is used chiefly in steam power generator plants and is transported by rail to these plants, located mostly in the Tennessee Valley Region.<sup>15</sup>

As has been noted, the amount of coal mined by contour stripping has rapidly increased in the past decade. Barring legislation or court intervention this trend should continue as long as stripping is more profitable than underground methods. Strip mining recovers upwards of 90% of a coal deposit while deep mining gets only 35% to 85% of the coal. Production per man-day can be as much as 25 tons for stripping versus 11 tons by deep mining. Contour stripping in the study area where coal seams range from 18 to 60 inches yields 2,400 to 8,100 tons per acre.<sup>16</sup>

Strip mining of coal consists of removing the dirt and rock cover from a deposit and then mining the exposed seam with frontloaders

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<sup>15</sup>Robert C. Johnson and Edward T. Luther, Strippable Coal in Northern Cumberland Plateau Area of Tennessee, Report of Investigations 34 (Nashville, Tenn.: State Department of Conservation, 1972), p. 5.

<sup>16</sup>"An Appraisal of Strip Mining," Tennessee Valley Authority (Knoxville, Tennessee, 1963), p. 4.



TABLE 2

CHANGES IN TOTAL ACREAGE DISTURBED BY CONTOUR  
STRIP MINING OF COAL RESERVES  
(1961 - 1973)

County	County Size	1961	1966	1973
Anderson	214,400	2,510	4,882	7,759
Campbell	288,600	3,674	8,487	14,229
Claiborne	284,200	1,776	3,405	5,155
Morgan	348,200	3,059	4,290	6,025
Scott	345,000	5,139	6,674	8,152

Source: Tennessee Bureau of Mines Files

and bulldozers. In the study area this is done on the mountainsides and is called contour stripping. A haul road is first cut up the mountain to the coal seam. Then explosives are used to loosen the overburden of dirt and rock. Heavy equipment then removes the overburden, placing it downslope in a spoil bank. The flat area left at the seam is called the bench. The steep mountainside remaining upslope from the mining cut is called the high wall. Figure 4 shows a typical contour stripping site and potential changes which can take place due to linear extension of cut (A) or upslope widening of cut through second-cut operations (B). Second cut operations become possible on early sites because of development of better equipment, which allows economic removal of the thicker overburden upslope from earlier operations at some sites. In other cases a mining site is extended along the contour. Finally, a mining site may become smaller because of natural or man-induced vegetative reclamation.

Tennessee did not have a strip mining law until 1967, and then it was not effectively worded. For example, it stated that a water quality permit must be applied for before mining could start; the permit need not be approved, just applied for. The law was revised and strengthened in 1972. The personnel at the Division of Reclamation, Knoxville Office were cooperative in providing information and their files during this study. A study of reclamation effectiveness in Appalachia as of 1965 shows Tennessee

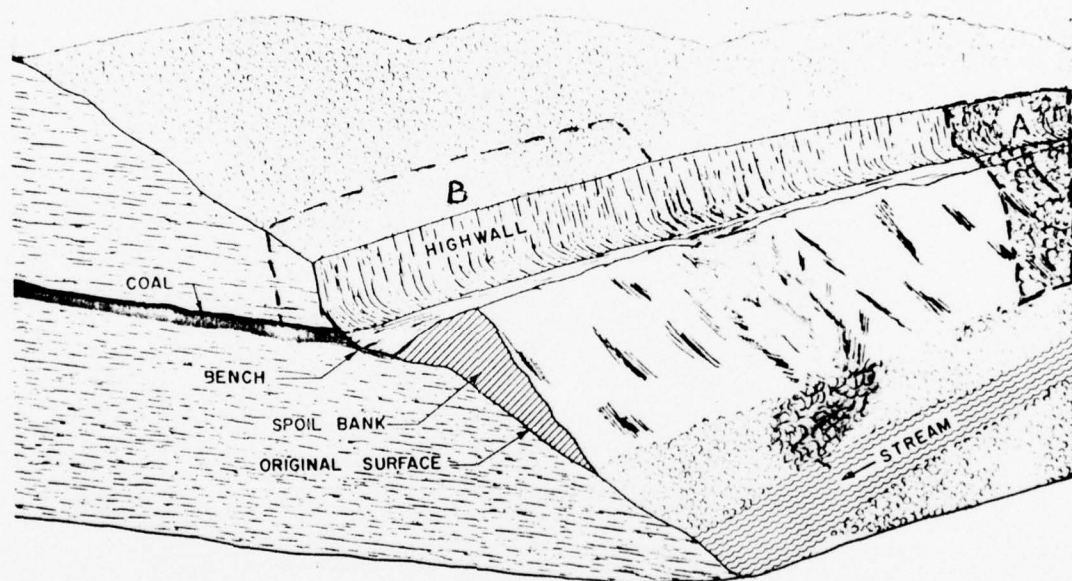


Figure 4. Typical Contour Stripping Mining Site.

to be last of the 13 states surveyed and indicates that of 26,760 acres disturbed by contour strip mining in Tennessee as of 1 January 1965, only 1,098 acres (4%) had been completely reclaimed and only 275 acres (1%) had been partly reclaimed; the remaining 25,387 acres of disturbed acreage remained unreclaimed.<sup>17</sup>

Since reclamation requirements in Tennessee are of such recent origin, and since the conifer stands being planted on new mine sites require from five to eight years to become established, the visible effects of reclamation as seen from the air are quite small in the study area. Because the present reclamation laws apply only where mining has taken place since 1967, there are extensive unreclaimed areas which were mined prior to the 1967 law. These so-called "orphan mines" are only being restored through nature's slow process, except where they are connected with subsequent mining operations, for here reclamation is required for the entire site. The predominant steep slopes in the study area serve to slow the natural revegetation process. In view of the facts, subtraction of mining acreages due to reclamation during the study period is assumed to be negligible. As time passes it may become possible to monitor reclamation effectiveness in the area from ERTS imagery.

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<sup>17</sup>"Study of Strip and Surface Mining in Appalachia," An Interim Report to the Appalachian Regional Commission, U. S. Department of the Interior (Washington, D.C.: U. S. Government Printing Office, 1966), p. 21.



In order to most completely evaluate the ERTS estimated strip mine acreages a "ground truth" basis of comparison was required. Fortunately, the five county study area of this investigation was part of a Tennessee Division of Geology project which actually surveyed each existing mine site in the summer of 1972. Data from the survey were made available to this investigator as a first stage ground truth data base. Tennessee Bureau of Mines files were then examined, restituting the exact additional acreages disturbed for each county up to the five individual coverage periods. The reported acreages disturbed by contour strip mining, shown in Table 3, are used as the basis of evaluation of ERTS estimates in Chapter Three. They are assumed to be correct and are henceforth referred to as "actual" acreages disturbed.

TABLE 3  
ACTUAL DISTURBED ACREAGE TOTALS CORRESPONDING  
TO ERTS COVERAGE DATES

Date	COUNTY				
	Anderson	Campbell	Claiborne	Morgan	Scott
15 Oct. 72	7,105	13,357	4,822	5,626	7,802
13-14 Jan. 73	7,362	13,642	5,143	5,786	8,067
14 Apr. 73	7,459	13,818	5,149	5,925	8,101
12-13 Jul. 73	7,759	14,229	5,155	6,025	8,152
11 Oct. 73	7,787	14,362	5,361	6,178	8,237

Source: Tennessee Bureau of Mines Ground Surveys

## CHAPTER THREE

### INTERPRETATION TECHNIQUES AND RESULTS

#### I. Imagery Selection

ERTS imagery coverage of the study area was accomplished on an eighteen day cycle from August 1972 to October 1973 and made available to the University of Tennessee through a research contract to Dr. John B. Rehder, Department of Geography. Preliminary examination of all available coverage dates eliminated a number of frames because of unacceptable weather conditions of excessive haze or cloud cover. This initial survey produced seven usable sets of ERTS frames as listed in Table 4.

Frames were available in both negative and positive black and white transparencies in four multispectral scanner (MSS) bands and also in color composite transparencies. In each of these formats both bulk and precision transparencies were available from NASA. Bulk imagery depicts the earth scene as picked up by the sensor; precision imagery has been "geometrically adjusted" to fit a particular map projection. Bulk imagery was used in this study because the precision adjustment process, although important to map makers, results in a loss of detail on the ERTS frame.

Initial examination of mining areas for each of the four bands for the seven usable ERTS dates indicated that Bands 5 and 7 gave the clearest and most complete representation of mining sites in

TABLE 4

## USABLE ERTS MSS-7 IMAGERY AVAILABLE FOR STUDY AREA

Date	I.D. Number	Counties Covered:				
		Anderson	Campbell	Claiborne	Morgan	Scott
15 Oct. 72	1084-15431	X	X	X		
13 Jan. 73	1174-15431	X	X	X		
14 Jan. 73	1175-15490	X	X		X	X
14 April 73	1265-15494	X	X		X	X
12 July 73	1354-15431	X	X	X	X	X
13 July 73	1355-15485	X	X		X	X
11 Oct. 73	1445-15471		X		X	X



the study area. Ahmad and Kantner also found that bands 5 and 7 were best for defining stripped land in Ohio.<sup>1</sup> Reports of ERTS investigators indicate that band 5 is best for studying mine changes through photographic enhancement procedures, but that band 7 is superior for direct interpretation from bulk imagery. Rehder noted that band 5 imagery, when enhanced by negative prints and varied print contrasts, allows mine site changes to be detected by the study through time of individual mine sites.<sup>2</sup> On the other hand, investigators working with the bulk imagery as received have found band 7 to be superior in mine definition to band 5. Russell, et al., have found that band 7 is best for regional mined land inventories.<sup>3</sup> Borden, et al., also found band 7 best for working directly with bulk imagery because band 7 registers lowest reflectance for mines of any band, while at the same time registering the highest reflectance for vegetative matter.<sup>4</sup> These characteristics give band 7 the greatest contrast between mines and their surrounding area.

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<sup>1</sup>Moid U. Ahmad and David A. Kantner, "Mapping of Spoil Banks Using ERTS-A Pictures," Remote Sensing of Earth Resources, Vol. II. Edited by F. Shahrokhi. Tullahoma, Tenn.: The University of Tennessee Space Institute, 1973, p. 1073.

<sup>2</sup>Personal communication with Dr. John B. Rehder on 2 April, 1974.

<sup>3</sup>O. R. Russell, F. J. Wobber, C. E. Wier and R. V. Amato, "Applications of ERTS-1 and Aircraft Imagery to Mined Land Investigations," Remote Sensing of Earth Resources, Vol. II. Edited by F. Shahrokhi. Tullahoma, Tenn.: The University of Tennessee Space Institute, 1973, p. 1105.

<sup>4</sup>F. Y. Borden, D. N. Thompson and H. M. Lachowski, "Identification and Mapping of Coal Refuse Banks and Other Targets in the Anthracite Region," Proceedings of the Symposium on Significant Results Obtained from ERTS-1. Greenbelt, Md.: NASA/Goddard Space Flight Center, 1973, pp. 1065-9.

Further detailed comparison of mine site definition on band 5 versus band 7 for each of the seven coverage dates indicated that in each case band 7 was superior. Therefore, imagery in the format of black and white positive transparencies representing MSS band 7 was used exclusively for the detailed interpretation and static acreage estimation of surface mining sites. Fortunately these seven usable dates produced five distinctly seasonal records through the circumstance of favorable weather: April 14, 1973 (Spring), July 12, 13, 1973 (Summer), October 15, 1972, October 11, 1973 (Fall), and January 12, 13, 1973 (Winter).

## II. Mine Site Recognition

Only simple interpretation procedures, using generally available equipment, were considered. The equipment used were a standard light table for imagery backlighting, an eight-power hand magnifier and a commercially available gridded mylar. Techniques which were not utilized, including computer densitometric analysis, polar planimeter procedures and selective darkroom print and imagery enhancement, might be applied to ERTS imagery and could well lead to better estimation accuracies than this study obtains. This study, however, used and analyzed the accuracy of simple areal-estimation procedures which should be understandable and usable by a broad segment of lay photo interpreters. The results obtained could be expected to serve as a guide to those considering use of small-scale ERTS imagery in strip mining study elsewhere and in other research and management tasks.

The principal recognition keys to strip mines are their linearity and distinct contour following signatures. These characteristic irregular shapes might possibly be confused with small plowed mountain farm plots in some areas. However, near mine sites in the study area, such farm holdings are practically non-existent. The area's 90% forest cover is ideal in terms of providing good mine site-background contrast. Older mine cuts in the area are quite narrow, ranging from 50 to 150 feet in width; newer cuts are generally much wider with widths of 150 to 500 feet. Obviously, the newer wide cuts are easier to recognize on ERTS imagery. The resolution power of the unaided human eye is 0.1 mm;<sup>5</sup> at the ERTS scale of 1:1,000,000 this represents 100 meters. However, with the aid of an eight power magnifier, one can theoretically resolve widths of 13 meters, or 40 feet, which would include the older, narrow cuts where registered on ERTS.

The spectral tones of bare land sites on band 7 range from medium to very dark gray against the light to very light gray of surrounding forest vegetation. This considerable tone contrast is important in recognizing mining sites. Additionally, where mine sites have water impounded on benches, mines may have a dark mottled texture; the darkest portions represent the water impoundments on the sites.

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<sup>5</sup>Felipe D. Pena, "The Selection of Scales for Aerial Photography to be Used in Geographic Interpretation," Contributions of the Mexican Delegation to the 21st International Geographical Congress. New Delhi, India, 1968, p. 144.

Visual recognition of mine sites depends on the apparent structure of an area; that is, its characteristic spatial arrangement: the size and shapes of contour strip mines and its spatial context: the tonal contrast and aggregate variation with surrounding area. It is especially important when using the relatively low resolution ERTS imagery for the investigator to have a good prior knowledge of the parameters under study and of the study area itself. This involves study of processes involved, and alternate sources of information. In this study, familiarization with the study area was accomplished through study of Tennessee Bureau of Mines maps and records, and preliminary mapping of mined areas on the county aerial photo index sheets (scale 1:63,360) for each of the five counties, available from the Agricultural Stabilization and Conservation Service.

### III. Point Sampling of Total Disturbed Acreage

A point sampling technique was used whereby 1/10 inch square mylar grid was randomly superimposed on imagery of the study area for each time frame. In conjunction with the sample grid a sheet of clear acetate containing a trace of the region's water features and the county boundaries within the study area was used to delimit the study area on each ERTS frame.

A problem was encountered in determining the sample size to use per county. Hammond indicated that 100 sample points are adequate to describe slope characteristics of a single map quadrangle



within 2% accuracy.<sup>6</sup> However, slope characteristics represent a continuous phenomena and mining sites are discrete phenomena. Furthermore, ERTS imagery represents a much smaller scale than the smallest scale of 1:125,000 used by Hammond for direct sampling. Therefore, to insure that an adequate sample size was taken, approximately 1,000 points were sampled for each county and time period. For some other purposes, much smaller samples may suffice.

The sampling grid was superimposed on each county area five or six times to obtain a large sample of about 1,000 points for each time period — the sample points being defined as the grid intersections. The total sample points were defined as the sum of all grid intersections falling within a county's boundary and 1/2 of the grid intersections falling on the county boundary line. Each sample point was subjected to a binary classification: it either appeared on or not on a mine site. Points falling on site boundaries were equally divided between the categories. The surrounding area was studied as well as each sample point to make the classification decision. Each ERTS time frame required about three hours to interpret through this point sampling scheme. The resulting ratio of mine points to total sampling points provided a percentage of area mined for each county. These percentages were multiplied by total acreage per county to obtain estimated mining acreages as shown in Table 5.

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<sup>6</sup>Edwin H. Hammond, "Procedures in the Descriptive Analysis of Terrain," p. 17.

TABLE 5  
POINT SAMPLING ESTIMATES OF MINED ACREAGES  
FOR EACH COVERAGE PERIOD

	County				
	<u>Anderson</u>	<u>Campbell</u>	<u>Claiborne</u>	<u>Morgan</u>	<u>Scott</u>
County Size	214,400	288,600	284,200	348,200	345,000
<u>Date</u>					
15 Oct 72	11,213	14,141	5,997	*	*
13-14 Jan 73	2,852	4,416	3,467	4,735	4,968
14 Apr 73	4,288	8,139	*	5,084	6,589
12-13 Jul 73	7,140	15,324	4,746	5,397	8,246
11 Oct 73	*	15,613	*	4,735	6,934

\* Imagery Coverage Not Available

The percentage estimates were compared to the total actual mined area percentages noted earlier in Table 3. The results of this comparison are shown in Table 6. Estimation error was defined as  $(\text{Estimated Percent} - \text{Actual Percent}) / \text{Actual Percent}$ .

The best imagery estimates of mining within the study area were provided by interpretation of the July (Summer) ERTS frames. The Spring and Fall imagery yielded the next best results, and the Winter frame produced the greatest estimation error. The July frame most nearly represents the time of year of peak vegetative growth, which enhances contrast between vegetated areas and the bare earth of strip mine areas. For the survey of mining in the study area the object-background relationship is best differentiated during the summer period. Mean estimation error was 7% for the July frame, considerably less error than for the other time frames. The dominant factor within the study area is degree of contrast as influenced by amount and vigor of vegetative growth on areas surrounding mine sites. As noted earlier, reclamation activities within the study area are negligible. Areas where reclamation has been initiated have not reverted to substantial vegetative cover and so appear on ERTS as mine cuts.

The generally low accuracy of static acreage estimates makes value of such county-wide sampling schemes for change detection questionable. Table 7 shows a comparison of change in percent mining figures between successive seasonal frames taken from ERTS with the actual change in percent figures. It is obvious here that

TABLE 6

## POINT SAMPLING ESTIMATES OF PERCENT MINED AREA

Date	COUNTY											
	Anderson			Campbell			Claiborne			Morgan		
	Est.	Actual	% Error	Est.	Actual	% Error	Est.	Actual	% Error	Est.	Actual	% Error
15 Oct. 72	5.21	3.31	+58%	4.90	4.63	+6%	2.11	1.70	+24%	*	*	29%
12-14 Jan. 73	1.33	3.43	-61%	1.53	4.73	-68%	1.22	1.81	-31%	1.36	1.66	-18%
14 Apr. 73	2.00	3.48	-42%	2.82	4.79	-41%	*	*	*	1.46	1.63	-13%
12-13 July 73	3.33	3.62	-8%	5.31	4.93	+8%	1.67	1.81	-8%	1.55	1.73	-10%
11 Oct. 73	*	*	*	5.41	4.98	+9%	*	*	*	1.46	1.77	-18%
										2.01	2.39	-16%
												14%

\* Imagery coverage not available.

TABLE 7

COMPARISON OF ACTUAL VERSUS POINT SAMPLING ESTIMATES  
OF PERCENT CHANGE IN DISTURBED ACREAGE

DATE	COUNTY											
	Anderson		Campbell		Claiborne		Morgan		Scott			
	EST %	ACT %	EST %	ACT %	EST %	ACT %	EST %	ACT %	EST %	ACT %	EST %	ACT %
Oct. 72-Jan. 73	-4.00	+.12	-3.37	+.10	-.89	+.11		*		*		
Jan. 73-Apr. 73	+.67	+.05	+1.29	+.06		*	+.10	+.02	+.47	+.01		
Apr. 73-Jul. 73	+1.33	+.14	+2.49	+.14		*	+.09	+.05	+.48	+.01		
Jul. 73-Oct. 73		*	+.10	+.05		*	-.09	+.04	-.38	+.03		

\* Data Not Available



mining landscape changes cannot be accurately derived from ERTS through a county-wide point sampling procedure. However, study of individual mine sites on successive ERTS frames has been demonstrated by Rehder to delineate change.<sup>7</sup> Therefore while this study, with its county-wide sampling procedures does not accurately estimate mining landscape changes through time, Rehder, using imagery enhancement procedures and individual site study, has delineated and monitored this change.

The principal value of the sampling procedure used here then is static acreage inventory, wherein ERTS imagery can provide the accuracies noted in Table 6. This technique does not seem to have direct application to monitoring acreage changes.

#### IV. Areal Estimation Sampling of Total Disturbed Acreage

Upon completion of the point sampling technique described earlier, a direct areal estimation procedure was also evaluated for the July 1973 ERTS frames, the date with the best point sampling results. The purpose was to see what comparative accuracy could be derived by using grid cells and visual estimation of mining percentages within each sample cell.

The same ten-to-an-inch mylar sample grid was used, each 0.1 inch by 0.1 inch block forming a sample cell in which the percent of mined

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<sup>7</sup> John B. Rehder, Geographic Applications of ERTS-1 Imagery to Landscape Change. 162-III, Final Report, NASA Contract #NAS5-21726. (Greenbelt, Md.: Goddard Space Flight Center, May, 1974), Part III, Section 3.0.

area was visually estimated to the smallest interval possible to optimize estimation precision. Using the 0.1 x 0.1 inch sample cell and the July frame of the study area this interpreter found that he could consistently estimate percentage mined area within the cell to within the nearest 10%. Therefore this class interval was cut in half, to allow for visual interpolation to the nearest 5%. The method used was one of visually gathering up the mining area in a sample cell and combining it into one or more quadrants of the cell, and estimating the percent of the cell occupied by mine sites. The sample cells which intersected county boundaries were combined to form an equivalent number of complete cells. The mined area estimates for each sample cell were then totalled and divided by the total possible area within a sample of about 1,000 cells, producing an estimate of mined area percentage for each county for the July frames.

Results of the areal sampling procedure are summarized in Table 8. Imagery for dates other than July, which had been analyzed in detail with the point sampling procedure were not evaluated by the areal estimation technique. The July areal estimation results exhibit twice the error demonstrated by the point sampling procedure. Additionally, the areal estimation sampling technique required about three times as long (nine hours) for a single frame as the point sampling technique.

#### V. Seasonality of Image Interpretation

Seasonal conditions in the study area influence the amount of information which may be obtained from ERTS. The summer ERTS frames

TABLE 8

RESULTS OF AREAL ESTIMATION SAMPLING OF 12 JULY 1973  
 ERTS WITH POINT SAMPLING COMPARISON

County	Actual %	Areal Estimation Sampling		Point Sampling	
		% Estimated	Error	% Estimated	Error
Anderson	3.62	3.11	-14%	3.33	- 8%
Campbell	4.93	4.10	-17%	5.31	+ 8%
Claiborne	1.81	1.58	-13%	1.67	- 8%
Morgan	1.73	1.50	-13%	1.55	-10%
Scott	2.36	2.07	-12%	2.39	+ 1%
Mean Estimation Error =			14%		7%

sharply contrast disturbed mining sites with surrounding vegetation, but in the fall, winter, and spring frames less contrast is evident. Four seasonally representative ERTS MSS 7 frames are shown in Figure 5. For other investigations the summer season may not prove to be optimal. One must develop an appreciation for the seasonal changes involved with a given study purpose and select coverage accordingly.

Winter (January 1973 frames): This coverage gave the greatest error in mining estimate - 43% mean error of estimation. This period represents the yearly ebb in vegetative vigor and leaf mass. The presence of considerable leaf fall, spread onto the mine sites, cuts down contrast and obscures ground detail due to little tonal variation. Frost or snow gives some places a light tone, also obscuring detail. For forest inventory of deciduous versus coniferous reserves, the rather homogeneous ground scene may prove optimal.

Spring (April 1973 frame): This coverage gave the second most inaccurate mining estimate - 29% mean error of estimation. Vegetative vigor is not yet to a point of providing adequate contrast to suitably delineate barren mine sites. Early Spring may be the best period for some hydrologic studies; drainage patterns can be seen most clearly due to peak runoff conditions and lack of obscuring vegetative canopy along minor channels. Soil surveys may also be accomplished using spring imagery, because fields have a minimal cover and high moisture content which serves to reveal differing field drainage conditions. Rock outcrops also show up well during this period.



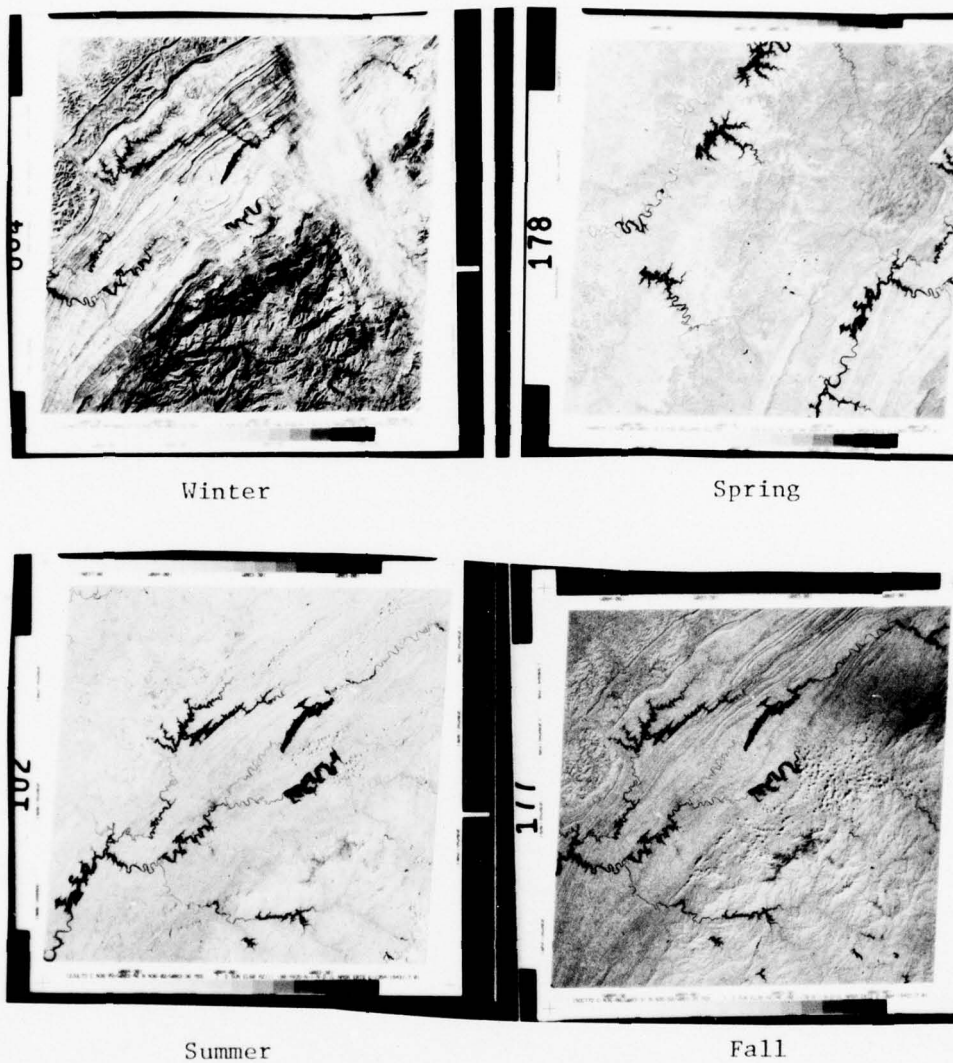


Figure 5. Representative Seasonal Coverage for ERTS MSS-7.  
(70 mm format at scale of 1:3,800,000).



Summer (July 1973 frames): This ERTS coverage gave by far the best mining estimates - 7% mean error of estimation. The season has the peak annual vegetative vigor and accumulated live growth, which provides sharp tonal contrast with bare, disturbed surfaces of mine sites. Tree and undergrowth cover is so complete as to mask rock outcrops and obscure the smaller drainage channels. This period would seem best for differentiating between residential and commercial land use in large urban areas. The tonal signatures differ noticeably between the near concrete jungle of the central business district or commercial ribbon developments and the residential areas, with trees and lawns at peak vigor.

Fall (October 1972 and 1973 frames): The October 1972 frame permitted no better estimate than the April 1973 frame - 29% mean error of estimation. However, interpretation from the October 1973 frame produced the second best acreage estimates in this study - 14% mean error of estimation. In general the fall period exhibits a decrease in tonal contrasts from the optimal summer period, as far as strip mine site delineation is concerned. This decreased contrast is due to lowering vegetative vigor and the onset of leaf fall. For forestry purposes the different foliage tones may assist in species inventories of hardwoods.

## VI. Summary

At different seasons of the year various landscape elements may be best observed. No season is without limitations, but with

sufficient planning and a clear understanding of the subject under study the inherent ERTS imagery characteristics of broad areal coverage on a periodic, seasonal basis can be maximized.

The best estimates were obtained from the July ERTS coverage, when estimate errors ran from +1% to -10% for the five counties (Table 6). For other specific purposes where  $\pm 10\%$  is an acceptable estimate ERTS imagery has the potential to warrant further investigation. For surface mining the critical factor in obtaining the best estimate is seasonality of vegetation, the summer period providing the best results. The other seasons of the 1973 year gave less favorable results, yielding mean errors of 14% in the Fall, 29% in the Spring and 43% in the Winter. For some other uses, notably crop inventories and broad land use classification, the Spring and Fall seasons may produce the most consistent results. However, for strip mines in the Tennessee study area the Summer period is decidedly best for the one-year period of coverage available.

In view of the comparative accuracy and the considerable savings in time, the point sampling technique is considered to be the best of the two methods used in this study effort to measure area. The application of this technique to other specific resource management or planning purposes is clearly dependent on the degree of error acceptable. The demonstrated accuracies in this study are indicative of the information content of ERTS imagery with regard to county-wide sampling of one discrete distribution in one study area. These results for surface mining in Tennessee, although serving as an

indicator, cannot be directly applied to conclusions about ERTS imagery information content pertaining to any other subject. Furthermore, as was noted, strip mining activity has been studied on ERTS imagery by other techniques yielding results on individual site changes.

## CHAPTER FOUR

### SUMMARY AND CONCLUSIONS

#### I. Summary

There has been a tendency in the literature to suggest the promise of ERTS imagery interpretation without providing any statistics as to the accuracy achieved. This study has examined and quantified the application of ERTS imagery to a specific task in a certain area — static acreage estimates of surface mines in the upper Cumberland Plateau area of Tennessee.

Planners, conservationists and geographers, among others, are interested in obtaining near real-time, synoptic views as well as cyclic coverage of a myriad of activities on a regional basis. Although the absolute degree of accuracy of ERTS photo measurements for activities other than strip mining cannot be deduced from this single study, the sampling techniques used could be adapted to studies of other phenomena recorded on ERTS or other imagery. These techniques can be used to provide preliminary data on surface mining activities over larger areas and as a source of static regional mining estimates between more accurate surveys from ground or lower altitude aerial surveys.

Inventories are generally statistical summaries of information within smaller areal units. In the case of a regional, mined area, it may not be necessary, for some purposes, to very precisely

delineate mine site boundaries, but rather to get total areal extent estimates for a given date. ERTS data holds promise in providing static areal estimates on a regional basis.

ERTS interpretation can serve to forward the goal of improved understanding of patterns of regional activities without unacceptably high demands and costs in terms of man hours and imagery procurement. Such small scale remote sensing applications can serve to accelerate research and reduce its costs, indeed allowing consideration of problems in areas which cannot be accessed by traditional field techniques because of time and dollar constraints, or simply prior unavailability of data in any other form.

The strength of ERTS coverage is the periodic coverage provided on a broad scale basis. Inherent in these characteristics are speed of interpretation per unit area, reduction of field work, timeliness of data acquisition, and the objective generalization or filtering of the earth scene performed by the very high altitude vantage point.

The generally low level of areal estimation accuracy demonstrated in this study is offset by the time and material economies of interpretation and the regional viewpoint provided. When estimation errors are considered it is well to keep in mind that in any cartographic generalization process there is involved a loss of detail in each step from larger to smaller scale. Even starting with detailed ground truth data at the individual mine site level and reducing it to a presentation at the 1:1,000,000 scale would involve a considerable loss in definition.



An important factor in determining whether ERTS imagery is the best initial source for a given purpose is the size of the area involved. Low and medium scale commercial or NASA overflights can obviously be applied to smaller area studies. As an example, for this study's area, several larger scale imagery records exist; TVA index sheets of the 7 1/2 minute quadrangles containing portions of the study area are available at a scale of 1:63,360 and recent NASA RB57 flight lines producing medium scale (1:60,000 and 1:120,000) color and color IR imagery also cross the study area. But if timely, periodic coverage is required on a regional or statewide basis then such large and medium scale coverage may well be too costly to consider.

As further work with small scale ERTS imagery can consistently establish stable levels of confidence for interpretation, the system may become the first economically viable alternative for regional synthesis on a real-time basis. In some cases a multiple stage sampling process could incorporate a preliminary overall areal survey with ERTS, with carefully selected sub area coverage by lower level, higher resolution sensor underflights.

Optimal results with ERTS imagery depend not only on positive identification of phenomena but also on the interpreter's ability to perform the more difficult tasks of feature recognition by drawing inferences from their texture, contrast and immediate surroundings. The dividends gained in ERTS or other small scale imagery work from an individual's knowledge of the study topic outweigh the alternative of using a skilled interpreter-technician who has no knowledge of the parameters being sampled or of the study area. This may not be

the case with higher resolution imagery, for here the technician may obtain better estimates and better cartographic representations. However, with low resolution imagery, the professional investigator, skilled in the field or topic under study has an advantage in the recognition problem. Furthermore, the use of a priori knowledge of the particular phenomena and study area to obtain optimal results is a completely valid technique as long as the sampling methods are unbiased.

## II. Conclusions

The final decision on further specific applications of ERTS imagery to a given task will involve a detailed analysis of the tradeoffs between the lower time and imagery coverage costs of ERTS and the decreased resolution of the imagery presentation. It is obvious that for some tasks, ERTS offers the first reasonable chance for study. The speed of interpretation as well as access to remote or unmapped areas involves the possible savings of months or even years of fieldwork. The periodic coverage potential is important for the study of the dynamics of regional activities. There are no problems with the variable contrast found so often when one constructs a mosaic, because each ERTS frame has one illumination source. The principal limitations are a general lack of true stereoscopic viewing capability, high optical resolution, and fair weather dependency. However, the weather constraint is not unique to ERTS, but rather is a problem shared with all other higher resolution aircraft sensors except radar. Furthermore, for some purposes.

the reduction of information to the lower level of resolution on the ERTS frame may be superior to any subjective human cartographic generalization.

This study has demonstrated that ERTS imagery has utility for providing static mining acreage estimates within the Tennessee study area, particularly during the summer period. The aggregate value to some tasks of such small scale sampling procedures, with the demonstrated unimpressive variation in seasonal accuracies may be subject to question. However, ERTS imagery does exist as an alternative study means, if only as a first stage analysis or "quick look" at one or several parameters within a large area. In some areas of the world, where large or medium scale mapping is incomplete or nonexistent ERTS coverage may represent the first and only step forward in understanding the present character of the earth's surface and man's role in altering that character through time.

The interpretive applications of remote sensing to resource management, planning, and conservation-law enforcement are evident. If field inspection could be largely supplanted by imagery interpretation in these areas, a considerable savings in man hours would result. Also, such a means of bringing the field indoors provides the opportunity of exposing phenomena to many curious eyes and probing minds in a multitude of career fields that might otherwise never gain exposure to the study areas.

In all the advances in applications of remote sensing either accomplished or planned, however, it is important to remember that

remote sensing imagery is a tool for use in geographic synthesis and not a product in itself. Far from being replaced by such devices, the responsibility of the geographer looms greater than ever — to rise to the challenge of advancement offered by such a powerful assistant. Not every photo interpreter can fully assess an air photograph; it takes skilled personnel, such as planners, conservationists and geographers, well schooled in the processes which influence the physical and manmade features of the landscape.<sup>1</sup> Only then does one know best what to look for. The prospects set forth in James and Jones' work apply equally as well today:

Photo interpretation is not in conflict with, nor does it supersede, the use of other methods of gathering, analyzing, and presenting geographical data. Geographical studies should never be done exclusively from the air unless this restriction is enforced by conditions beyond the geographer's control. Air photographs record only the visible aspects of the face of the earth, and there are many non-material aspects with which the geographer is concerned. But the procedures of photo interpretation offer geographic research a new and valuable tool which, methodically and artfully employed in conjunction with other techniques, will make possible a great advance in the quality and precision of geographic work.<sup>2</sup>

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<sup>1</sup>Yehuda Kedar, "A Geographic Approach to the Study of Photo Interpretation," Photogrammetric Engineering, XXIV (December, 1958), p. 823.

<sup>2</sup>Preston E. James and Clarence F. Jones, American Geography: Inventory and Prospect (Syracuse: University Press, 1954), p. 543, 534-40.



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